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The lysine requirement for reproduction in swine

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INTRODUCTION

Mankind is changing his traditional eating habits due to escalated population growth, and, potentially, he is becoming a direct competitor with livestock and poultry for cereal grains and protein sources such as soybeans. This is especially true for swine and poultry, since humans could utilize similar feedstuffs. In order for the swine industry to survive, new noncompetitive energy and amino acid sources need to be evaluated for possible use in the swine diets of the future. Single cell protein, synthetic amino acids and nonprotein nitrogen may be possible substitutes for soybean meal in future swine diets. At present, only a few of the synthetic amino acids compete with plant and animal protein sources, but with technological advancement and more efficient production their use may become commonplace.

Some possible energy sources may be nonedible lard and tallow. They are used to a limited extent at present but usage may increase in the future due to economic pressure. The synthetic diet of today could be the standard diet of the future.

For swine to utilize these diets properly, exact amino acid requirements will have to be determined for the various stages of the pigs life cycle. Numerous amino acid requirement studies have been reported on baby pigs and growing-

finishing pigs, but our precise knowledge of the essential amino acid requirements for reproducing swine is lacking. The N.R.C. (1973) states that their amino acid recommendations for reproducing swine are adequate for normal litter development but not necessarily optimum levels. The recommendations are based on amounts needed for satisfactory retention of nitrogen during the last period of pregnancy. The last trimester of pregnancy may be the period of greatest lysine needs as well as of other essential amino acids. However, the overall gestation requirement may be less. If enough lysine is fed during the early periods of reproduction to retain nitrogen above the needs of fetal development, tissue stores may be adequate to meet the extra demand during the later period of pregnancy when the diet is limiting in lysine. If this hypothesis is valid, the present lysine requirement may be in excess.

REVIEW OF LITERATURE

Protein Response on Reproduction

Early nutrition studies indicated that gravid swine require protein constituents other than that found in yellow corn for economical reproductive performance. Bar and Daunay (1905) reported that gravid swine can utilize nutrients more efficiently than nongravid swine. Evvard et al. (1914) found that corn plus supplemental blood meal fed to pregnant sows increased the size and vigor of the litter at birth. Blood meal contains a high quantity of lysine and tryptophan. Nutrients other than protein may have influenced pig size and vigor, but a better amino acid balance may also have been beneficial. Since these early reports, diet quality has improved substantially and within a wide range of protein levels, research indicates no direct effect on swine ovulation or conception rate. Davidson (1930) fed 204 and 327 grams of protein per day and found no differences in ovulation rate. Compared to nutrient standards used today, Davidson's (1930) high protein diet was above and his low protein diet was slightly below N.R.C. (1973) recommendations (280 g per day).

Boaz (1962) fed 10.8, 15.3 and 19.8% protein to gravid swine housed either in a dry lot or a pasture. Protein intake had little effect on reproductive performance, although

a slight decrease in breeding efficiency was noted in the dry lot sows fed the low protein level. McGillivary et al. (1964) fed different sources and levels of protein to gravid swine. The results of both studies indicated no increase in reproductive performance due to increased protein intake during gestation. In other experiments, Rippel et al. (1965a), Pond et al. (1969), Svajgr et al. (1970) and Svajgr et al. (1972) all reported that the amount of protein consumed during gestation did not affect the size of litter farrowed, but did reduce breeding efficiency. Following a severe protein restriction, some sows failed to exhibit estrus unless pregnant mare's serum was administered to the sows.

Most recent work has indicated little influence of dietary protein on the maintenance of pregnancy. However, beneficial responses due to the gestation diet have influenced the sows' lactation performance. Clawson et al. (1962) found that energy consumption during gestation influenced pig birth weight while protein consumption had little influence on birth weight. However, sows consuming 1.2 pounds of protein per day during gestation as compared to 0.30 pounds had heavier litters at weaning. Pond et al. (1968) fed protein free diets during pregnancy. Normal pregnancy was maintained, but milk production was significantly reduced if the sow did not consume a normal level

of protein during gestation. Baker et al. (1970b) demonstrated that litters from sows consuming 8.7% crude protein during pregnancy had inferior lactation growth rates when compared to litter growth rate of sows consuming 16% crude protein diets. If the 16% crude protein treatment was fed during the last trimester of pregnancy, lactation performance was equal to sows fed 16% crude protein during a complete pregnancy. Baker et al. (1970a) fed graded levels of protein and a fortified Opaque-2 corn diet during pregnancy. No differences in reproductive performance were noted, but lactation performance improved as gestation dietary protein increased. The Opaque-2 fed sows had lactation performance similar to the sows fed 16 and 20% protein diets during gestation due to better amino acid balance in the Opaque-2 corn. A direct relationship was found with protein intake and gestation weight gain, but the sows with the greatest gestation gain had the greatest lactation weight loss.

Frobish et al. (1966) and Holden et al. (1968) fed graded levels of crude protein (8, 12, 16 and 20%) during gestation. No differences were noted for the number of pigs farrowed due to treatment. Both researchers reported better lactation performance as a result of increased protein intake during gestation and Holden et al. (1968) reported increased milk protein as a result of increased protein intake.

Frobish et al. (1966), Pike and Boaz (1969) and Hesby et al. (1970a) reported that protein quality during gestation had an influence on pig survival rate during lactation, but increased survival rate is not reported by all workers. Pike and Boaz (1969) demonstrated that low protein quality fed during the last trimester of pregnancy had the greatest impact on lactation milk production and pig viability. Hesby et al. (1970a) indicated that fortified Opaque-2 corn fed during gestation was equal to a 15% crude protein corn-soybean meal diet. Frape et al. (1971) reported that birth weight of pigs born in older sows was associated with the rate of food intake during gestation. A daily protein intake of 208 g and lysine of 8.3 g during gestation appeared to meet the needs of gravid sows. Amino acid balance is as important as the level of protein fed during gestation for improving lactation performance.

In Speer's (1971) review, it was concluded that a fortified all corn diet fed during gestation will maintain a normal litter size and birth weight for one parity. However, lactation performance is depressed due to the low protein gestation diet even when an adequate lactation diet is fed. The carry-over response may be due to inadequate lysine and tryptophan in the corn protein.

The Response of Protein and Amino Acid Nutrition on Sow Milk Quality, Milk Yield and Pig Lactation Performance

Little is known about the nutrients fed during gestation and their effects on milk production during lactation, but from the literature reviewed in the previous section, it can be concluded that gravid swine fed a protein deficient diet have the ability to nutritionally buffer their feti throughout a complete pregnancy. The sows will then farrow a normal litter of viable pigs. However, lactation performance is reduced if gestation protein intake was low and the lactation diet is adequate. A possible reason for the reduced lactation performance is reviewed by Salmon-Legagneur in a Pig Industry Development Authority (1967) report. The sow, compared to other large domestic animals, is one of the best milk producers. She secretes approximately 6 g of dry matter per kg of body weight, while a cow secretes 3 g. Sow's milk contains 1200 cal/g and the pigs suckle approximately 20 times per day. The litter doubles in weight by one week postpartum. As a result, the sow's nutrient requirement for lactation is high and appetite is not maximized for about one week postpartum. The sow must, therefore, draw upon her body stores as a supplement to the diet for the production of sufficient milk constituents. As a result, it is normal for a sow to lose weight due to increased lipid and protein catabolism during

lactation. However, if an inadequate gestation diet was fed, sows have been found to gain weight during lactation when a normal diet was fed (Salmon-Legagneur, 1967).

Smith (1960a, b) studied the effects of protein and energy intake during gestation on milk and pig performance during lactation. The results indicated that low protein or low protein and energy during gestation resulted in reduced weight gain by the pigs during lactation. The author concluded that milk yield and milk composition were dependent on the condition of the sow at parturition.

Elliott et al. (1971) studied the effects of varying protein consumption 30 days prior to parturition on the composition of sow colostrum and milk. Diets containing 5, 10 and 15% crude protein were fed. Milk samples were taken 12 hours and 7, 14 and 21 days postpartum. Sows produced slightly more protein in the colostrum when fed the 15% crude protein diet, while milk protein was equal for all treatments at each collection. Fat and ash content in colostrum and milk was not influenced by protein intake. Total solids less fat and essential amino acids were higher in the colostrum for the sows fed the 15% crude protein diet. Pig gain was least for sows fed the 5% crude protein diet, which the author assumed was due to poor milk production. Mahan and Mangan (1974) demonstrated that the interaction of gestation crude protein x lactation crude

protein was significant ($P < .05$) for lactation weight change and litter gain. Sows fed 9% crude protein diets during gestation performed equal to sows fed higher protein during pregnancy, when higher levels of protein were fed during lactation. Mahan and Mangan (1975) suggested that sows consuming better protein quality during gestation had more amino acids available from tissue stores for greater milk synthesis during lactation. Poor nursing pig gains were especially evident if a lower protein diet was fed during both pregnancy and lactation.

Greenhalgh et al. (1974) fed graded levels of protein during gestation and a high or a low protein level during lactation. Increased gestation protein increased lactation milk yield in their study.

The Influence of Pregnancy and Nutrition on Nitrogen Metabolism

Dietary protein intake and dietary amino acid balance influence the nitrogen metabolism of gravid swine. Kline et al. (1972) fed a standard diet to reproducing swine. An evaluation of protein anabolism was made by nitrogen balance trials conducted regularly throughout pregnancy. Nitrogen retention was maintained at 3 g per day until 15 to 20 days postcoitum. Nitrogen retention then increased from 7 to 10 g per day as pregnancy

progressed. The gravid sow's tissue contained more water as compared to nongravid animals. Shearer et al. (1971) reported that a pregnant sow's nitrogen retention remained at approximately 9.5 g per day until 110 days postcoitum. Nitrogen retention increased to 12 grams per day during the last days of pregnancy indicating a greater nutrient need the last stage of pregnancy. Elsley et al. (1966) also reported increased nitrogen retention as pregnancy progressed.

Lodge (1969) stated that the crude protein requirement for gravid swine is 265 g per day during the first 90 days. The requirement increases to 350 g per day from day 90 to 105 and to 400 g the last ten days of pregnancy. The products of conception account for about 1/6 of the nitrogen retained. Lodge (1969) stated that sows consuming 193 g of protein per day did not show increased nitrogen retention after day 70 or pregnancy as did sows consuming 662 g of protein per day.

Rippel et al. (1965b) and Miller et al. (1969) reported that nitrogen retention of gravid gilts plateaued at approximately 12.5% crude protein during the last trimester of pregnancy. Gilts fed no protein (Rippel et al., 1965b) lost 6.5 g of nitrogen per day. Jones and Maxwell (1974) fed pregnant gilts 8, 14, 17 and 20% crude protein and nitrogen retention was 9.3, 16.4, 21.1 and 28.1 g per day, respectively.

Rippel et al. (1965c) used pregnant gilts in nitrogen balance trials during the last trimester of pregnancy to study their amino acid requirements. The diets contained 12% crude protein and were fed at a rate of 1.82 kg per day. The nitrogen balance data indicated that 0.42% lysine, 0.37% isoleucine and 0.28% sulfur-bearing amino acids met the gravid gilts amino acid needs during the last stage of pregnancy. The addition of threonine or histidine to a diet containing 0.65% lysine did not enhance nitrogen retention or utilization.

In another trial, Rippel (1967) reported that 230 g of protein and 6100 kcal of metabolizable energy from a corn-soybean meal diet maximized the nitrogen retention of gravid swine. The addition of lysine and tryptophan to the diet slightly improved nitrogen retention. From nitrogen retention values, the gravid gilt was found to require 0.42% lysine, 0.37% isoleucine, 0.28% sulfur-bearing amino acids, 0.34% threonine, 0.46% valine, 0.17% histidine, 0.37% phenylalanine and 0.07% tryptophan (Rippel, 1967).

Pregnant sows are known to increase nitrogen retention as protein intake increases. An improvement of essential amino acid balance has also been shown to increase nitrogen retention. Hesby et al. (1970b) fed gravid gilts fortified

corn, fortified Opaque-2 corn and a 15% crude protein corn-soybean meal diet. The sows consuming Opaque-2 corn retained more nitrogen than the corn-fed sows, and they retained as much or more nitrogen than the 15% protein-fed sows. Hesby et al. (1972) fed Opaque-2 corn, normal corn plus 0.2% lysine, normal corn and a corn-soybean meal diet. Gestation weight gain was found to increase when lysine was added to the normal corn and higher protein diet. No response of serum gamma, beta and alpha globulins and albumins was observed due to increased lysine in the normal corn diet.

Baker et al. (1966a,b) reported negative nitrogen balance in nongravid adult swine fed dietary voids of threonine, isoleucine, lysine or phenylalanine. The excretion of urea and ammonia was directly related to the quality of amino acid patterns fed. Diet consumption was excellent regardless of the amino acid balance.

Allee and Baker (1970) added specific amino acids to an all corn diet for pregnant and nonpregnant sows. The addition of 0.25% lysine increased nitrogen retention in both pregnant and nonpregnant gilts. The addition of 0.041% tryptophan and 0.25% lysine also increased nitrogen retention suggesting lysine and tryptophan were the limiting amino acids. Duee and Rerat (1974) added levels of lysine to a 10.5% crude protein diet fed to gravid gilts

at a rate of 2 kg per day. Plasma free lysine, measured at 60 days postcoitum, accumulated at the 0.43% lysine level but at 90 days postcoitum did not accumulate until 0.63% lysine level. Gestation weight gain improved by 10 kg when dietary lysine increased from 0.23 to 0.43 to 0.63%. Nitrogen retention increased from 9.5 to 16.2 g per day as lysine intake increased and pig weaning weight increased from 7.3 kg to 8.1 kg. The authors estimated the requirement for lysine to be 0.42% when 2 kg of diet was fed per day. Čajko (1969) also reported increased gestation gain and improved lactation performance as dietary lysine intake increased during gestation.

Miller et al. (1969) fed various mixtures of corn and soybean meal to gravid gilts at a rate of 1.9 kg per day. As protein increased, nitrogen retention was maximized at 15% crude protein. This diet contained approximately 0.64% lysine, which is above the reported requirement of most authors.

Salmon-Legagneur and Duee (1972) fed graded levels of lysine during pregnancy and lactation. Nitrogen metabolism, blood urea and hemoglobin were observed on day 20 and 80 of pregnancy. All sows consumed 230 g of protein per day and the diets contained 0.44, 0.51, 0.58 and 0.65% lysine. The diets were fed at a rate of 1 kg/100 kg of body weight. No significant differences were noted in

nitrogen retention. Blood urea decreased in all treatments during the last trimester of pregnancy, indicating better protein and amino acid utilization. Lysine fed at 0.44% of the diet was adequate for normal reproductive performance.

Plasma Amino Acid Response to Fasting, Diet and Amino Acid Balance

Typpo et al. (1970) stated that the concentrations of free plasma amino acids are influenced by dietary supply and availability, rate of absorption from the gastrointestinal tract, withdrawal from the plasma for growth and synthesis, protein catabolism during a fast, amino acid imbalance and the time lapse from feeding to when a plasma sample is collected. Yorkshire barrows were fed a 16% crude protein diet and all of the free plasma amino acids except cystine increased above the fasted concentrations by two hours postfeeding. All amino acids except arginine, leucine, threonine and tyrosine returned to the prefeeding concentration by 8 to 12 hours postfeeding. Plasma methionine, lysine and isoleucine increased above the prefeeding concentration during the last 18 hours of the 24 hour fast.

Richardson et al. (1965) found that plasma free amino acids were consistently lower for pigs fasted 12 hours as

compared to 24 hours. In a similar experiment using fasted chicks, Hill and Olson (1963b) observed marked elevations in lysine and threonine 24 to 36 hours after the feed was taken away. During the same time period glutamine, isoleucine, leucine and valine were elevated slightly while arginine, histidine, phenylalanine, tryptophan and tyronine were depressed. When a nonprotein diet was fed, total plasma amino acids were less than the fasted plasma amino acid concentrations, presumably because the amino acids were not being used for energy. Young and Scrimshaw (1972) stated that lysine and sometimes threonine accumulate in the plasma during short term starvation due to tissue breakdown. Lysine and threonine have a slower rate of deamination than do other amino acids, thus causing accumulation in the plasma.

Shimada and Zimmerman (1973) found that the greatest plasma free amino acid concentration in pigs occurred one hour postfeeding. The plasma free amino acid concentration decreased up to 12 hours postfeeding followed by only a slight elevation at 18 hours postfeeding. The portal circulatory amino acids were consistently higher than the systemic circulatory amino acids.

Clark et al. (1966) studied the effect of different essential amino acid deficiencies on amino acid pools in rats. By eight hours postfeeding, the limiting amino acid

in the diet was reduced in the plasma and liver tissue. The amino acid concentration in the liver tissue correlated with the plasma amino acid concentration to a greater extent than did muscle amino acid concentrations.

Amino acid balance or protein quality has been shown to affect the rate of intestinal absorption as well as plasma amino acid concentration. Longenecker and Hause (1958) fed dogs varying amounts of different amino acids and determined the plasma amino acid concentration at different intervals postfeeding. Plasma lysine decreased and tryptophan and threonine increased when unsupplemented diets were fed. The authors stated that the decrease in plasma lysine indicated metabolic utilization of free plasma lysine so other amino acids could be used for protein synthesis. Plasma amino acids may serve as an amino acid store for a short term protein deficiency.

Wynne and Cott (1956) and Young and Schrimshaw (1972) studied the effect of food intake on plasma amino acid concentration. Plasma amino acids were found to reflect the concentration in the diet and interactions among amino acids were found to occur as a result of dietary intake. The data indicated that low dietary lysine resulted in decreased plasma concentration of lysine in the rat, human and dog. Plasma free methionine was also found to decrease in the rat, pig and human when a low intake of dietary lysine

was consumed.

An excess intake of a specific amino acid causes an accumulation in the plasma. Morrison et al. (1961), Puchal et al. (1962), Hill and Olson (1963a), Zimmerman and Scott (1965), Mitchell et al. (1968) and Stockland et al. (1970) studied plasma amino acid concentrations in response to varying the dietary amino acid intake using several species of animals. In several lysine studies, plasma free lysine remained at a low and constant level until dietary lysine increased to a level supporting maximum body needs. Plasma lysine increased linearly beyond the level of body needs. However, Muramatsu et al. (1973) found that plasma lysine increased well before the point of maximum growth with rats.

Mitchell et al. (1968), Stockland et al. (1970) and Lewis and Speer (1974) determined that the plasma amino acid response involved two linear mathematical functions. When the data were plotted on a graph, the intercept of the two functions was found to be very close to the amino acid requirement of the animal. The point of plasma amino acid inflection was found to occur before the points of optimum nitrogen retention and growth in most examples. Plasma amino acids were more responsive following meals than were fasted amino acid levels.

The data in the previous papers indicated that plasma

threonine may give an indication of the lysine requirement. Plasma threonine was found to have an inverse relationship to the plasma lysine concentration. Long (1966) demonstrated an inverse relationship between lysine and threonine concentration in pig plasma. Gray et al. (1960) determined an increased plasma tyrosine level as well as threonine when a lysine deficient diet was fed to growing cockerels.

Dean and Scott (1966) demonstrated with chicks that a lysine deficient diet resulted in a marked plasma amino acid lowering of the limiting amino acids and an increase of most other amino acids. Excess dietary lysine increased plasma lysine but had little response on the other amino acids except arginine, glutamic acid and asparagine which decreased slightly.

Longenecker and Hause (1959), Guggenheim et al. (1960) and Munro (1970) have reviewed the theory of amino acid balance. Free amino acids are the currency through which protein metabolism operates and no significant storage of free amino acids takes place. Therefore, dietary amino acids are an important source of amino acids for protein synthesis. Longnecker and Hause (1959) postulated that the individual essential amino acids are removed from the blood by the tissues at rates proportional to the amino acid requirements of the animal. The rate of protein synthesis in tissue is affected by the quantity and quality of the amino

acid supply. If protein quality is low, the amino acids will not be utilized efficiently for protein synthesis and urea synthesis will increase due to amino acid catabolism. Lewis and Speer (1974) and Sohail et al. (1974) found an inverse relationship between dietary lysine and plasma urea with lactating sows. Plasma urea was high whenever lysine was deficient and decreased linearly when the lysine needs were met. Baker et al. (1966c) also found that protein quality was inversely related to urea synthesis.

Brown and Cline (1972) used growing pigs fed various levels of lysine to determine the effect of urea excretion and plasma urea. When 0.5% lysine was added to an all corn diet, urea excretion in the urine decreased from 3.97 to 2.89 g per day and plasma urea decreased from 13.4 to 10.0 mg per 100 ml. Prior et al. (1975) used growing rats in a similar trial. Urea excretion was found to increase if the diet was deficient in lysine, tryptophan or arginine. The addition of lysine to a lysine deficient diet decreased urine urea excretion at a faster rate than did tryptophan, valine, phenylalanine and arginine additions to diets deficient in these specific amino acids.

EXPERIMENTAL

Objectives

The following experiment was conducted to determine the L-lysine requirement of female swine before mating and during pregnancy. The experiment was conducted through two reproductive cycles.

The response to levels of lysine was based upon the following measurements: nitrogen balance, plasma free amino acid levels and plasma urea nitrogen during gestation, and baby pig gain, milk production and milk composition during lactation.

Gestation

The study was designed as a split-plot experiment. Four dietary treatments were the main plots and the four periods of reproduction (premating, 30, 60 and 95 days postcoitum) were the subplots. Twenty-four sexually mature Yorkshire x Landrace gilts from the Iowa State University Swine Nutrition Farm were allotted to the four treatments from six outcome groups (four littermates per outcome group). The sows remained on the allotted treatment for two consecutive pregnancies. Analysis of the data was conducted by the method of least squares of unequal subclass numbers as described by Harvey (1960).

Experimental Diets

The calculated analyses of the experimental gestation diets are shown in Tables A1 and A2. The basal diet consisted of ground yellow corn fortified with vitamins, minerals and essential amino acids less lysine according to the requirements of reproducing swine as reported by N.R.C. (1968). The basal diet was supplemented with L-lysine·HCl in equal logarithmic spacing of L-lysine concentration (0.20, 0.30, 0.41 and 0.55% L-lysine). The diets were made isonitrogenous by additions of diammonium citrate. Each sow received 1.82 kg per day of the respective diet before mating and during pregnancy.

Experimental Units and Procedures

The sows were housed in a block building with an open front pen. The floor of the building and pen was constructed of concrete. Fresh water was available at all times. Woodshavings were used for bedding during the winter months. All sows were fed in the morning in individual feeding stalls. They remained in the stall until all feed was consumed.

Before mating, the sows were checked twice daily for estrus. Each animal was started on her assigned diet when estrus was observed. Following a 12 day adaption period,

a five day nitrogen balance trial was conducted. After the nitrogen balance trial, the sows were handmated to Poland China x Hampshire boars at least two times. Successive five day balance trials were then conducted 30, 60 and 95 days later. Body weight was recorded at major periods of reproduction throughout the experiment, and backfat measurements made before mating and at the end of each trimester of pregnancy. For the second reproduction cycle, the sows were started on the assigned treatment immediately after their first litter was weaned at 21 days of age. The same procedures as outlined for the first reproductive cycle were repeated during the second reproductive cycle.

The gestation nitrogen balance trials were conducted in elevated plywood stalls equipped with a tether to restrain the animal. Feces fell onto and through an expanded metal sheet at the rear of the stall and collected on a fine mesh screen. The feces was collected daily, weighed, stored in a plastic bag and frozen at -20 C until the five day collection was completed. At the end of the collection, the total five day feces collection was mixed and a 700 g subsample taken. The subsample was freeze dried. The dry sample was ground in a Wiley mill and stored in a sealed glass jar until analyzed for nitrogen.

Urine was collected with a size 24 Foley catheter

inserted into the bladder via the urethra. The catheter drained through Tygon tubing into a 20 liter bottle. The bottle contained 40 ml of 10% HCl (1.16 N). The urine was measured daily and a 0.5% subsample taken, which was stored at -20 C for later nitrogen analysis.

On day 17 of the initial observed estrus cycle and 35, 65 and 100 days after mating, two heparinized blood samples were taken by anterior vena cava puncture. The first blood sample was taken following a 24 hour fast and the second sample was taken one hour postfeeding. An 11.4 cm, 16 gauge needle attached to a 50 ml glass syringe was used to withdraw the blood samples. The syringe dead space was coated with a heparin solution (6.49 mg/ml). The blood samples (40 ml) were centrifuged immediately and the plasma was separated. Ten milliliters of plasma were then deproteinized immediately by addition of solid sulfosalicylic acid according to the method of Perry and Hansen (1969). The plasma and deproteinized plasma were stored at -20 C until analyzed. Plasma was analyzed for urea nitrogen as described by Marsh et al. (1965). Deproteinized plasma was analyzed for free lysine with a Technicon Sequential Multi-Sample Amino Acid Analyzer equipped with a short column. Plasma free-amino acids except lysine and tryptophan were determined on pooled samples obtained in the following manner: one milliliter of deproteinized plasma from each

sow fed the same lysine level was combined at each period of reproduction and similarly during both reproductive cycles. There were, then, eight pooled fasting samples for each treatment and eight pooled postfeeding samples for each treatment. The pooled deproteinized plasma was analyzed for all free amino acids with a Technicon Sequential Multi-Sample Amino Acid Analyzer similar to a modification of a method described by Stein and Moore (1954). The analyzer was equipped with an acid-neutral and basic amino acid columns.

Lactation

The sows were placed in raised farrowing stalls four days before the scheduled date of parturition and remained in the stall throughout a 21 day lactation. The sows and their litters were allowed free access to water at all times, but no creep feed was given to the litter.

Sow body weight was recorded before parturition, immediately postpartum and on day 21 of lactation. The backfat thickness was measured by probe before parturition and on day 21 of lactation.

Immediately postpartum, the total number of pigs born, number of pigs born live, total litter weight and weight of live pigs born were recorded. Litter size was equalized on day four postpartum. The litter was adjusted to seven

pigs for parity one and eight pigs for parity two. Litter size was maintained by replacing any pig that died with a pig of similar age and weight. The litters were weighed at 7, 14 and 21 days postpartum.

The sows' milk yields were measured on day 14 postpartum as described by Lewis and Speer (1973). The pigs were allowed to suckle at hourly intervals and were weighed immediately before and immediately after suckling. Four pigs were weighed in a wooden box at one time. The pigs were housed away from the sow between suckling periods in a heated pen. Hourly milk yield estimates were obtained for 15 consecutive hours. The initial three hours were regarded as a training and adjustment period, and the hourly values obtained during the final 12 hours were used in calculating a 24 hour milk yield.

On day 15, four and one half hours postfeeding, one blood sample was taken and processed as described in the gestation blood sampling procedure. Following withdrawal of the blood sample, the 16 gauge needle was retained in the anterior vena cava and the blood collection syringe removed from the needle. A syringe containing 10 IU of oxytocin was attached to the needle and the contents injected into the anterior vena cava. A milk sample was then expressed by hand. The milk sample was filtered to remove any foreign residue, bottled and stored at -20 C until

analyzed for nitrogen and total solids.

A nitrogen balance trial was conducted from day 15 to 20 of lactation. The raised farrowing stalls were equipped with a sheet of expanded metal at the rear portion of the stall. The feces and urine collection procedure was the same as described in the gestation procedure except baby pig feces had to be removed from the sow feces.

Postpartum, all sows received a common 13% crude protein diet. The ingredient composition is shown on Table A3. The lactation diet was made from corn and soybean meal and fortified with vitamins, minerals and methionine according to the N.R.C. (1968) recommendations for lactating swine. The protein content of the lactation diet was considered to be marginal in lysine content. Each sow received 4.54 kg per day during the first lactation and 5.00 kg per day during the second lactation. The diet was fed in equal portions two times daily.

Upon completion of the second lactation the sows were slaughtered at the Iowa State University Meat Laboratory. Carcass weight, carcass backfat, dressing percent, percent lean cuts and percent ham and loin were determined at this time.

The experiment was started in March, 1972, and finished in March, 1975. One gilt from the 0.20% lysine treatment failed to conceive for a second parity. Three gilts, two

from 0.20% lysine and one from 0.30% lysine, failed to exhibit estrus following parity one. Pregnant mare's serum (1500 IU), administered approximately 70 days following weaning, was used successfully as an estrus inducer. The gilts were successfully mated and conceived.

The nitrogen content of all feed, feces, urine and milk was determined by the methods of A.O.A.C. (1960). The milk total solids content was determined by the method of A.O.A.C. (1960) for determining milk dry matter.

RESULTS AND DISCUSSION

Plasma Amino Acids and Plasma Urea Nitrogen

The summaries of plasma lysine, plasma urea nitrogen, essential amino acids and nonessential amino acids as affected by lysine intake during reproduction are presented in Figures 1 and 2, and Tables A7, A9 and A10 (Appendix A). The summaries of plasma lysine and plasma urea nitrogen as affected by the period of reproduction are presented in Table A8.

Plasma free lysine after a 24-hour fast and postfeeding both increased linearly ($P < .005$) as dietary lysine increased. The postfeeding plasma lysine compared to the fasting plasma lysine increased with more magnitude as was also described by Lewis and Speer (1974) with lactating sows. In both the fasted and postfeeding plasma lysine, the point of inflection occurs between the lysine treatment of 0.30% and 0.41% (5.4 and 7.4 g/day). The plasma lysine ratio (postfeeding level/fasted level) responded linearly ($P < .005$) and cubically ($P < .05$) to dietary lysine intake. The maximum ratio was obtained at 0.41% lysine and was reduced as lysine intake increased to 0.55%. The reduced ratio may indicate lysine is no longer the limiting amino acid after the 0.41% level.

Plasma urea nitrogen decreased linearly ($P < .005$) in

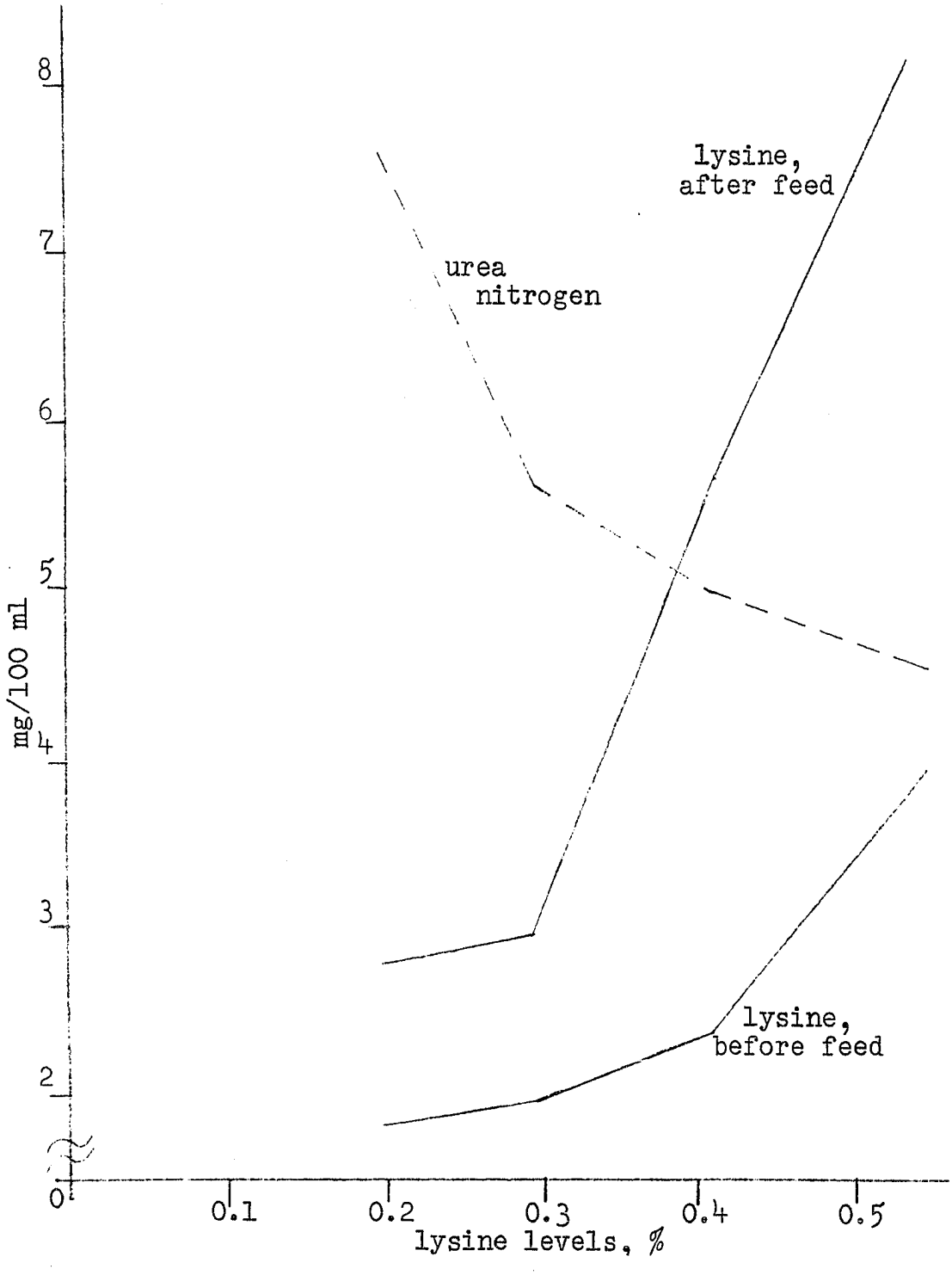

Figure 1. Effect of lysine intake on free plasma lysine and plasma urea nitrogen

both the fasted and postfeeding plasma sample as dietary lysine increased. Only a slight increase was noted among plasma urea nitrogen in the postfeeding plasma samples as compared to the fasted plasma samples. The inverse relationship between plasma free lysine and plasma urea nitrogen has also been reported by Brown and Cline (1972), Lewis and Speer (1973), and Prior et al. (1975). When amino acid balance improves, more amino acids are utilized for protein synthesis and less plasma urea nitrogen synthesis due to less amino acid catabolism.

Plasma lysine and plasma urea nitrogen (Table A8) were not significantly affected by the period of reproduction in either the fasted or postfeeding samples. A significant difference ($P < .05$) was observed for the overall mean of the postfeeding plasma lysine level of parity I as compared to parity II.

Fasting plasma values for other EAA, except histidine and arginine, decreased linearly as dietary lysine increased (threonine, methionine, $P < .005$; and isoleucine, leucine, phenylalanine, $P < .05$). Histidine increased linearly ($P < .05$) and arginine did not change. The total EAA less lysine and tryptophan in the fasting plasma samples decreased linearly as dietary lysine increased.

As lysine intake increased, all postfeeding plasma EAA except threonine increased. Threonine demonstrated a linear

($P < .005$) and cubic ($P < .05$) decrease while methionine and histidine increased linearly ($P < .05$). Isoleucine showed a linear increase ($P < .05$) and cubic ($P < .05$) response while leucine demonstrated a quadratic increase ($P < .01$) and cubic ($P < .05$) response.

In both the fasting and postfeeding plasma samples, the plasma threonine concentration was inversely related to the plasma lysine concentration. Similar results were reported by Gray et al. (1960), Long (1966) and Muramatsu et al. (1973) with cockerels, pigs and rats fed different levels of lysine. The accumulation of threonine with a lysine deficient diet may be related to the increase of nonutilizable threonine for protein synthesis in tissues and a decrease of liver threonine dehydrase. A plasma lysine:threonine ratio may be a sensitive indicator of lysine nutrition and the lysine level. When the ratio approaches unity, there is an indication the lysine requirement is beginning to be met (Muramatsu et al., 1973). The lysine:threonine ratio approached and surpassed unity between 0.30 and 0.41% lysine in this experiment (Table 1).

The fasted total EAA decreased linearly ($P < .05$) as the dietary lysine increased (Figure 2 and Table A9). As dietary lysine increased from 0.20% to 0.30%, the total EAA increased to the maximum concentration in both fasted and postfeeding plasma samples. The increased EAA concentration

Table 1. Ratio of lysine and threonine determined in plasma collected postfeeding during reproduction[a]

Item	Lysine, %			
	0.20	0.30	0.41	0.55
Lysine	2.73	2.97	5.58	8.30
Threonine	4.69	5.34	3.25	3.37
Ratio	0.58	0.56	1.72	2.46

[a]Ratio = lysine concentration/threonine concentration.

as lysine increased from 0.20% to 0.30% may have been due to an abnormal amino acid metabolism due to the severe lysine deficiency at the 0.20% level. As dietary lysine increased from 0.20% to 0.30%, the total EAA reached the maximum concentration at 0.30%. The total EAA declined both after fasting and postfeeding when dietary lysine increased from 0.30% to 0.41%. The EAA began to plateau after 0.41% dietary lysine. The plateau was more evident in the postfeeding samples, but the treatment differences were not significant. This response indicates more efficient amino acid utilization beyond the 0.41% lysine level. Lewis and Speer (1973) reported a similar plateau with EAA at a level equal to or exceeding the lysine requirement for lactating sows. They did not demonstrate the increase in

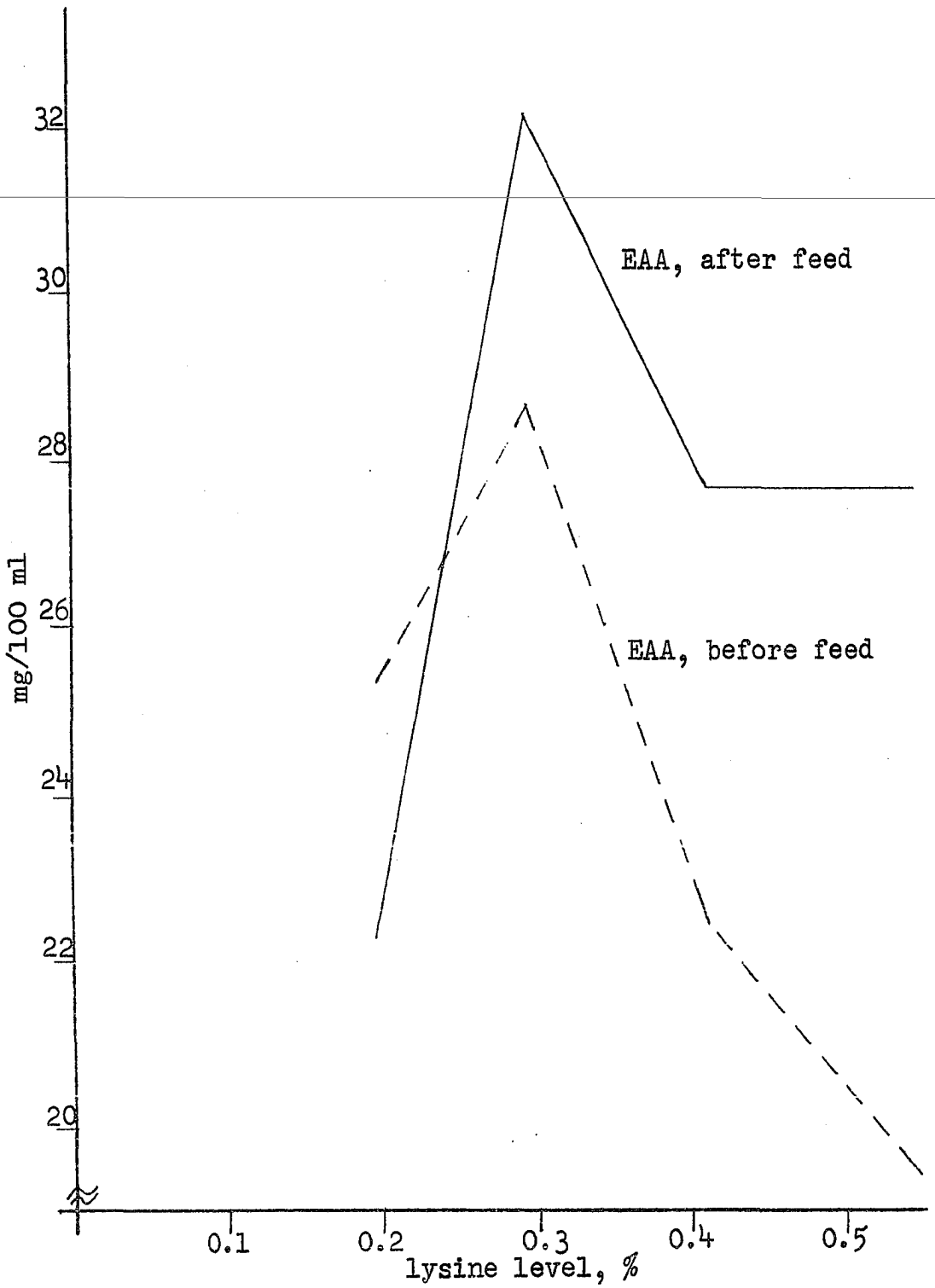

Figure 2. Effect of lysine intake on total free EAA minus lysine and tryptophan

EAA concentration at the lower lysine levels.

The NEAA in the fasted plasma in most instances increased parallel to the dietary lysine. However, glutamine and ornithine decreased as lysine increased. The NEAA in the plasma collected postfeeding were erratic and demonstrated no definite trends.

The summary of EAA, plasma urea nitrogen and NEAA during lactation are shown in Tables A11 and A12. The plasma lysine and plasma urea nitrogen were determined from individual samples and the other amino acids from pooled samples. Only lysine and plasma urea nitrogen were analyzed statistically. No significant differences were found for plasma lysine and plasma urea nitrogen. The total EAA concentration less lysine and tryptophan was greatest for sows consuming the low lysine diet during gestation.

Nitrogen Metabolism

The summary of gestation nitrogen metabolism as affected by lysine intake is presented in Figure 3 and Table A13. Increasing dietary lysine resulted in significant linear decreases ($P < .005$) in daily urinary nitrogen excretion and significant linear increases ($P < .005$) in daily nitrogen retention. No significant differences were found for daily fecal nitrogen excretion, but the sows fed

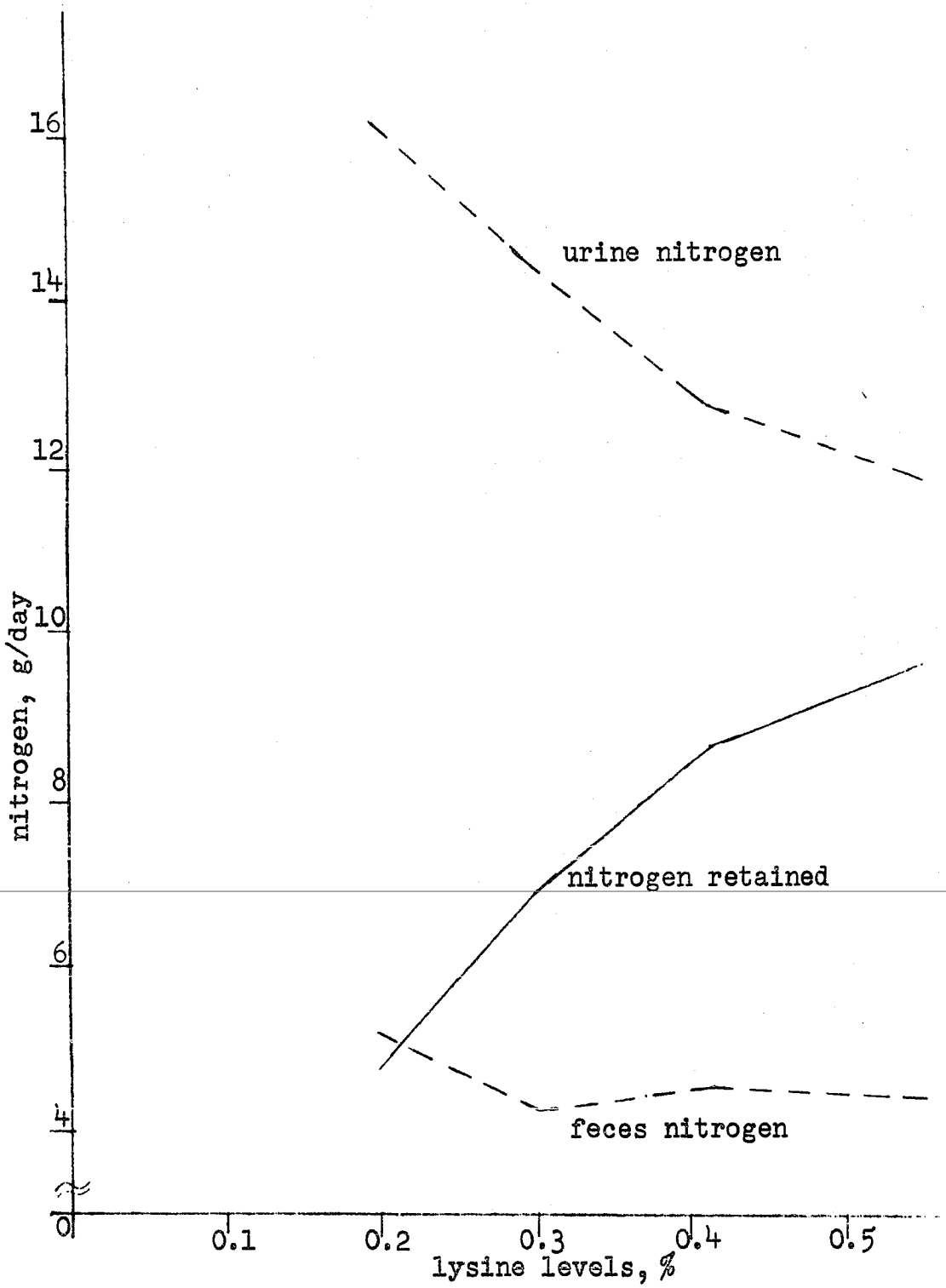

Figure 3. Effect of lysine intake on nitrogen metabolism during gestation

the 0.20% lysine diet did excrete more fecal nitrogen.

The overall mean for nitrogen retention is in accordance with observations of other researchers feeding low protein diets. Rippel et al. (1965b) fed gravid gilts various protein levels. Those consuming 9% crude protein retained 10.3 g of nitrogen per day. In a trial comparing amino acid supplementation to a 12% crude protein diet, Rippel et al. (1965c) found that daily nitrogen retention increased from 7 g to 10.5 g when the diet contained 0.42% lysine and adequate tryptophan. Jones and Maxwell (1975) observed a daily nitrogen retention of 9.3 g when gravid gilts were fed 8% crude protein.

The effect of period of reproduction on nitrogen metabolism is presented in Figure 4 and Table A14. A significant linear increase ($P < .005$) and cubic response ($P < .05$) of daily nitrogen retention was observed as reproduction advanced. Urine nitrogen excretion decreased linearly ($P < .005$) and quadratically ($P < .005$) as reproduction advanced. Nitrogen excretion via the feces increased linearly ($P < .005$) as reproduction advanced and as a result the apparent digestibility coefficient decreased linearly ($P < .005$) as reproduction advanced. The orthogonal comparison of urine nitrogen and retained nitrogen during nonpregnancy versus pregnancy was significantly different ($P < .005$) and fecal nitrogen for the same

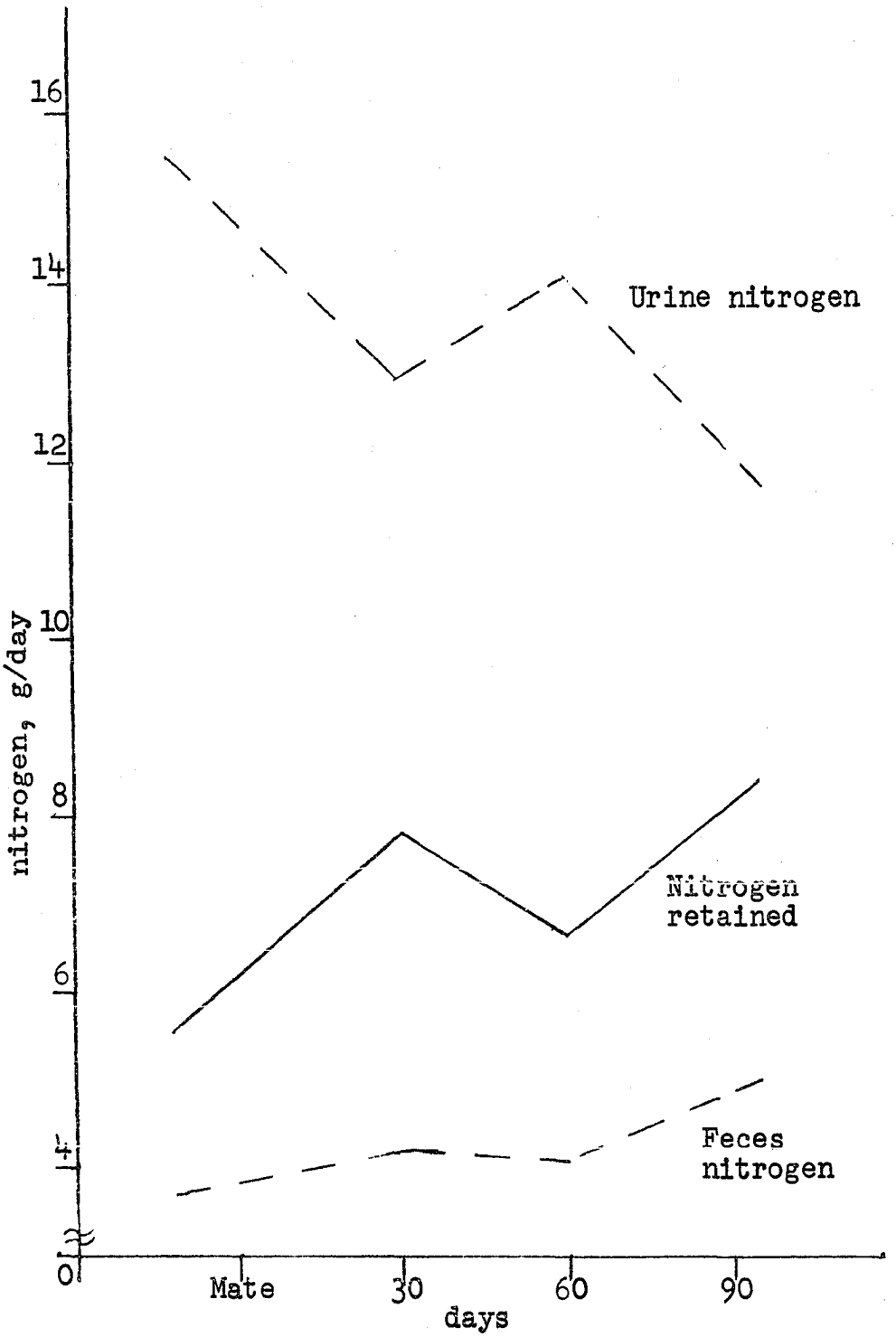

Figure 4. Effect of the period of reproduction on nitrogen metabolism

comparison was also significantly different ($P < .05$). The comparison among the stages of pregnancy (60 versus 30 and 95 days) for daily urine nitrogen and nitrogen retained was also significant ($P < .05$) accounting for the overall cubic ($P < .05$) and quadratic ($P < .005$) responses for nitrogen retention and urine nitrogen excretion. Daily urine nitrogen decreased significantly ($P < .05$) as the sows progressed from parity I to parity II.

The overall nitrogen metabolism data indicate that nitrogen retention was beginning to plateau between 7.4 and 10.0 g of lysine per day. If another treatment of higher lysine content were present, the plateau may have been more evident. From the data, 7.4 g of lysine per day or more is adequate for nitrogen retention.

If the products of conception and uterine and mammary growth require 3.5 g of daily nitrogen retention (Elsley et al., 1966, 1967) and nitrogen required for maintenance, which includes losses of hair, skin and hoof, is 1.0 g per day (Baker, 1966a), there remains 4.0 g of the 8.5 g of nitrogen retained by the sows on 0.41% lysine for growth and anabolism. The sows consuming 0.55% lysine (9.4 g daily nitrogen retention) would only have 0.9 g/day more nitrogen for growth and anabolism due to an increased daily lysine intake of 2.6 g. As will be seen in the next section, all sows, regardless of nitrogen retention,

farrowed normal litters. It seems excessive nitrogen is not necessary for normal reproduction (Holden et al., 1971).

Reproductive and Lactation Performance

A summary of reproductive performance is shown in Table A17 and the first four items of Table A19. As was expected, no significant treatment response was observed for reproductive performance (Table A17). It is well documented that low protein gestation diets do not have adverse effects on reproductive performance (Pond et al., 1968; Svajgr et al., 1972). However, the reproduction performance of the sows in parity II was better than in parity I (Table A19). No significant treatment differences were observed for total pigs born per litter and number of pigs born alive, but an increase of almost one pig per litter was farrowed by the sows in parity II as compared to parity I. A significant improvement was noted for parity II as compared to parity I for total litter weight ($P < .05$) and litter weight of live pigs ($P < .005$). An improved reproduction performance would be expected in second litter sows as compared to first litter sows.

No major difficulties were encountered in mating the sows. However, those that did have problems were from the lowest lysine treatments (three from the 0.20% lysine

level and one from the 0.30% level).

A summary of lactation performance and nursing pig gain as affected by lysine intake during gestation is presented in Figure 5, Table A15 and Table A18. Little research has been reported on the carry-over effect of lysine intake during gestation upon lactation performance. Elliott et al. (1971) fed different levels of protein to sows during gestation and reported that gestation protein intake had a positive influence on colostrum quality. More recently, Mahan and Mangan (1974, 1975) fed different levels of protein during gestation and found a significant depression on nursing pigs gain when the sow's protein intake was low during gestation and when the lactation diet was marginal to only adequate in protein. Duee and Rerat (1974) found depressed nursing pig gain when inadequate lysine was fed during gestation.

The results in this experiment demonstrate a definite carry-over effect on milk production, milk quality and nursing pig gain (Figure 5 and Table A18). A linear treatment response ($P < .05$) for the average weight per pig was observed at 7, 14 and 21 days of lactation. The maximum weight at 7, 14 and 21 days was obtained with the 0.30% lysine level. No significant differences were observed with the 21 day gain but the pigs nursing the sows fed the 0.20% lysine diet had inferior gain as compared to pigs nursing

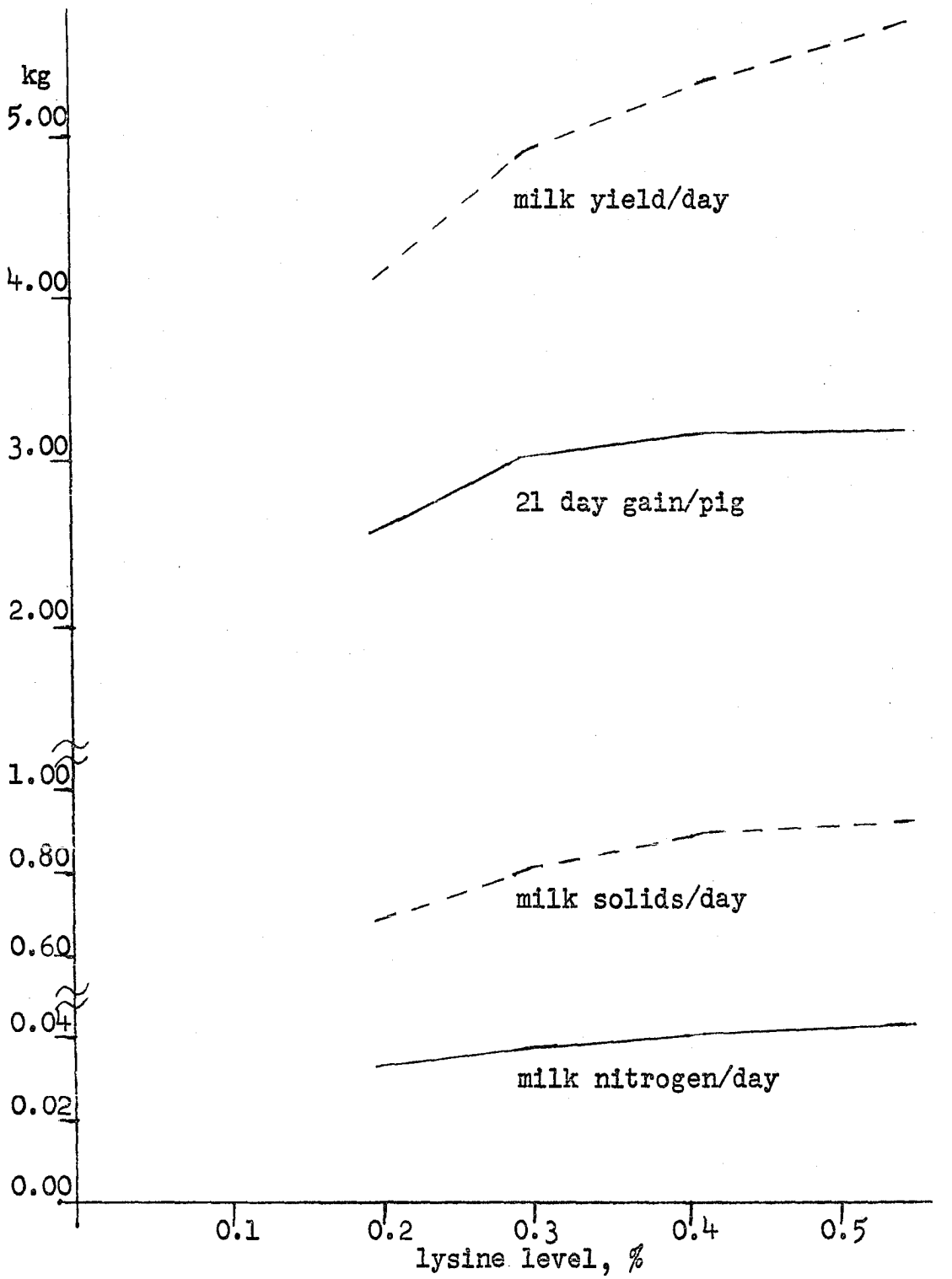

Figure 5. Effect of lysine intake during gestation on lactation performance

sows on the higher lysine diets.

Milk quality determined on day-15 of lactation was found to improve as the gestation dietary lysine increased. Total milk nitrogen increased linearly ($P < .01$) and total milk solids increased linearly ($P < .05$). Milk yield, determined on day-14 of lactation increased linearly ($P < .05$) as gestation dietary lysine increased. No differences were found in milk protein (%). The total solids and total nitrogen content of the milk tended to parallel the quantity of milk produced (Salmon-Legagneur, 1967).

No significant nitrogen retention differences were found during lactation, but the sows fed the lower gestation lysine levels did retain the most daily nitrogen. When total daily milk nitrogen was subtracted from daily nitrogen retention, a significant linear decrease ($P < .05$) in nitrogen balance resulted (Table A15). The sows fed the higher levels of lysine during gestation secreted more metabolic nitrogen via the milk due to greater body stores (Mahan and Mangan, 1975).

Significant parity effects were found for pig lactation performance and milk quality (Table A19). Significant improvements were noted for average pig weights during parity II at 7, 14 and 21 days ($P < .005$, $P < .005$ and $P < .05$, respectively). Milk nitrogen and milk solids

both increased significantly ($P < .005$) during parity II. No significant parity effects were noted for lactation nitrogen metabolism (Table A16). Nitrogen retention was greater during parity II due to increased feed intake.

Sow Body Measures and Carcass Measurements

A summary of weight changes and backfat changes as affected by lysine intake during gestation are presented in Table A20 and Table A22. No significant treatment response was observed for either weight change or backfat change during either gestation or lactation. The sows on the 0.20% lysine level maintained the lightest body weight throughout the experiment and tended to show some compensatory recovery during lactation (Baker et al., 1970a). The lactation nitrogen metabolism data also indicated the sows on the 0.20% lysine level were utilizing more nitrogen for tissue growth and less for milk synthesis.

A summary of sow weights and backfat measurements as affected by parity are presented in Tables A21 and A23. The net gain for parity I was significantly greater ($P < .005$) as compared to parity II (22.0 vs 2.0 kg), indicating the definite need for growth as well as maintenance during parity I.

A summary of carcass measurements are shown in Table A24. None of the values are significant but the sows on

the 0.20% and 0.30% lysine levels were fatter and had a lower trimmed ham and loin percent. The sows on the 0.20% lysine treatment had the lowest carcass yield and smallest loineye area. The live weight at slaughter for the low lysine fed sows was the heaviest, indicating compensatory recovery when this weight was compared to the weights during reproduction.

Determination of the Lysine Requirement for Reproduction

A summary of the optimum values for reproduction and lactation are presented in Table 2. Considering all of the criteria, the optimum lysine needs are met between 0.30% and 0.41% lysine (5.4 and 7.4 g/day). Plasma EAA less lysine and tryptophan decline and plateau at 7.4 g/day but this plateau has been shown to occur at a level equal to or exceeding the lysine needs for swine (Lewis and Speer, 1973). The optimum reproductive nitrogen retention is also reached between 7.4 and 10.0 g/day.

Considering the plasma free lysine concentrations, the dietary lysine needs are met above 5.4 g/day. However, accumulation of the limiting amino acid in the plasma has been shown to occur before the dietary needs are met for maximum growth (Stockland et al., 1970; Muramatsu et al., 1973).

Considering the carry-over response on lactation

Table 2. Estimate of the lysine requirement for reproduction determined from optimum criteria

Item	Optimum lysine range, %	Estimate of the point of interception of two linear functions
Plasma lysine (fasted)	0.30-0.41	0.38
Plasma lysine (postfeed)	0.30-0.41	0.30
Plasma urea nitrogen	0.30-0.41	0.31
Plasma EAA less lysine and tryptophan	0.41-0.55	0.41
Reproductive nitrogen retention	0.41-0.55	0.45
Milk yield	0.30-0.41	0.38
Total milk nitrogen	0.30-0.41	0.39
Total milk solids	0.30-0.41	0.39
Pig lactation gain	0.30-0.41	0.38

performance, the lysine needs for gestation are met above 5.4 g/day. In all instances, 7.4 g of lysine per day was adequate for normal reproductive and lactation performance. It must be assumed the lactation diet is adequate.

If the lysine requirement is determined for each criterion measured during geststion and lactation by estimating the intercept of two linear functions, the mean of the intercepts indicates 7.0 g of lysine per day is required

for reproduction. The mean of the gestation intercepts is 6.9 g/day and the mean for the lactation intercepts is 7.1 g/day. However, the point of the intercept cannot be determined precisely, since this experiment only included four dietary treatments of lysine. Therefore, the two linear functions are estimates. However, 7.4 g/day is very close to this estimate and adequate for normal reproductive performance and lactation performance, assuming an adequate lactation diet is fed.

If it is assumed that the added L-lysine·HCl was 100% digestible and that the true lysine digestibility of a standard corn-soybean meal diet is 90% digestible (Eggum, 1973), the lysine requirement for reproduction would increase to 0.43% (7.8 g/day).

Assuming that 7.4 g of lysine is totally available, this requirement is 0.2 g/day less than that reported by Rippel et al. (1965c). The requirement is also less than that reported by Salmon-Legagneur and Duee (1972) and Duee and Rerat (1974), 8.4 and 8.6 g/day, respectively. The N.R.C. (1973) recommends 0.42% dietary lysine, presumably, the same as suggested by Rippel et al. (1965c) but the daily intake for the N.R.C. (1973) is 8.4 g/day, because the feeding level is based on a feed intake of 2.0 kg/day.

SUMMARY

Twenty-four Yorkshire x Landrace gilts (six outcome groups of four littermates each) were used in an experiment to determine the lysine requirement for reproduction. L-lysine·HCl was added to a fortified corn diet in equal logarithmic spacings to attain the four lysine levels of 0.20, 0.30, 0.41 and 0.55% lysine. These diets were fed at the rate of 1.82 kg/day before mating and during two reproductive cycles. During each three-week lactation, all animals were fed a common 13% crude protein diet corn-soybean meal diet. Lactation feed intake was 4.54 kg during parity I and 5.00 kg during parity II. Litter size was equalized to seven pigs during parity I and eight pigs during parity II.

Nitrogen balance trials were conducted before mating and at the end of each trimester of pregnancy. At the end of each nitrogen balance trial, blood samples were collected after a 24-hour fast and one hour postfeeding. As dietary lysine increased, urinary nitrogen decreased linearly and nitrogen retention increased linearly ($P < .005$). Beyond 7.4 g/day of dietary lysine, the urinary nitrogen decreased and the nitrogen retention began to plateau. Plasma urea nitrogen decreased linearly and plasma lysine (fasting and postfeeding) increased linearly

($P < .005$) as dietary lysine increased. The inflection point of all three plasma components occurred between 0.30% and 0.41% lysine levels.

Milk yield, milk quality and pig weights during lactation responded to the level of lysine fed during pregnancy. Milk yield, milk solids and milk nitrogen was maximized in those sows fed the 0.41% lysine level. Pig weight was near maximum at 0.3% lysine. No significant differences were observed in nitrogen retention among treatments during lactation (day-15 to day-20 of lactation). Nitrogen retention less milk nitrogen decreased linearly ($P < .05$) and was minimal for the sows consuming 0.41% lysine.

No differences were found for the number of pigs born or the birth weight of the pigs. No differences due to treatment were observed in the sow weights and backfat thicknesses during gestation or lactation. The sows on the 0.2% lysine level were the lightest during pregnancy. At the termination of the experiment the animals were slaughtered and standard carcass measurements taken. No significant differences were found, but the sows on the low lysine diet had the smallest loineye area, lowest carcass yield and the thickest backfat.

Considering all parameters, 0.41% lysine (7.4 g/day) met the reproductive needs. When lysine is supplied by

a standard corn-soybean meal diet, a level of 0.43% (7.8 g/day) would be suggested since lysine is estimated to be 90% available to swine in a corn-soybean meal diet.

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APPENDIX A

Table A1. Composition of gestation basal diet[a]

Ingredient	Level
Ground yellow corn	89.00
Dicalcium phosphate (26% Ca, 18% P)	2.60
Calcium carbonate (38% Ca)	0.50
Dextrose	5.50
Sodium chloride (iodized)	0.50
Vitamin premix[b]	1.00
Trace mineral premix[c]	0.05
L-isoleucine	0.10
DL-methionine	0.10
L-tryptophan	0.05
L-valine	0.05
L-threonine	0.05
L-lysine·HCl[d]	---
Diammonium citrate (12.38% N)	---
Total	100.00

[a]The basal diet was calculated to contain 3219.5 kcal ME/kg. Chemical analysis indicated the basal diet to contain 8.7% crude protein and 87.2% dry matter.

[b]Composition of vitamin premix shown in Table A5.

[c]Composition of trace mineral premix shown in Table A6.

[d]L-lysine·HCl added to provide 0.20 (basal diet), 0.30, 0.41 and 0.55% L-lysine in the experimental diets. All diets were made isonitrogenous by diammonium citrate inclusion.

Table A2. Essential amino acid composition of gestation basal diet

Amino acid	Corn	Added	Total, %
Arginine	0.47	--	0.47
Histidine	0.17	--	0.17
Isoleucine	0.33	0.10	0.43
Leucine	0.88	--	0.88
Lysine	0.20	--	0.20
Methionine	0.25	0.10	0.35
Phenylalanine	0.37	--	0.37
Threonine	0.30	0.05	0.35
Tryptophan	0.08	0.05	0.13
Valine	0.35	0.05	0.40

Table A3. Composition of lactation diet fed to all sows[ab]

Ingredient	Level
Ground yellow corn	85.22
Soybean meal 49%	11.10
Dicalcium phosphate (26% Ca, 18% P)	1.75
Calcium carbonate (38% Ca)	0.80
Sodium chloride (iodized)	0.50
Vitamin premix[c]	0.50
Trace mineral premix[d]	0.05
DL-methionine	0.08
Total	100.00

[a]The lactation diet was calculated to contain 3299.0 kcal ME/kg. Chemical analysis indicated the diet to contain 13.18% crude protein and 87.45% dry matter.

[b]4.54 kg/day during the first lactation and 5.00 kg/day fed during the second lactation.

[c]Composition of vitamin premix shown in Table A5.

[d]Composition of trace mineral premix shown in Table A6.

Table A4. Essential amino acid composition of lactation diet

Amino Acid	Total, %
Argine	0.87
Histidine	0.30
Isoleucine	0.54
Leucine	0.99
Lysine	0.50
Methionine and cystine	0.43
Phenylalanine	0.64
Threonine	0.45
Tryptophan	0.16
Valine	0.66

Table A5. Composition of vitamin premix[a]

Ingredient	Quantity/kg of gestation diet	Quantity/kg of lactation diet
Vitamin A, IU	4409.0	2204.0
Vitamin D2, IU	1102.0	551.0
Riboflavin, mg	6.6	3.3
Pantothenic acid, mg	17.6	8.8
Niacin, mg	33.1	16.5
Vitamin B12, μg	22.0	11.0
Ethoxyquin, mg	0.4	0.2

[a]The vitamins are carried in 80% fine ground yellow corn. The nutrients contributed by the carrier were included in the diet formulation.

Table A6. Composition of trace mineral permix (35 C-95)[a]

Element	Percent in premix	Level in diet when added at 0.05%, mg/kg
Zinc	20.00	100.00
Iron	10.00	50.00
Manganese	5.50	27.50
Copper	1.10	5.00
Cobalt	0.10	0.50
Iodine	0.15	0.75

[a]Ingredients: zinc sulfate, ferrous sulfate, manganese sulfate, iron oxide (color), copper oxide, cobalt carbonate, calcium iodate and calcium carbonate.

Table A7. Summary of free plasma lysine and urea nitrogen during gestation as affected by lysine intake, mg/100 ml[abc]

Item	Lysine, %			
	0.20	0.30	0.41	0.55
Lysine, after fast	1.8	2.0	2.4	3.9
Lysine, postfeed	2.8	3.0	5.6	8.3
Lysine, ratio	1.7	1.8	2.9	2.6
Urea nitrogen, after fast	7.4	5.5	4.9	4.5
Urea nitrogen, postprandial	7.8	5.7	5.0	4.5
Urea nitrogen, ratio	1.0	1.0	1.0	1.0

[a]Refer to Table B1 and B2 for the statistical analysis.

[b]Plasma collected after a 24 hour fast and 1 hour postfeeding.

[c]Ratio = postfeed value/fasted value.

Table A8. Summary of free plasma lysine and urea nitrogen as affected by the period and parity of reproduction, mg/100 ml[abc]

Item	Premating	30 days postmate	60 days postmate	95 days postmate	Parity I	Parity II
Lysine						
fast	2.40	2.77	2.43	2.38	2.70	2.31
postfeed	4.61	5.79	4.69	4.61	5.36	4.44
ratio	1.92	2.09	1.93	1.94	2.31	2.19
Plasma urea nitrogen						
fast	5.69	5.20	5.44	5.69	5.60	5.50
postfeed	6.20	5.36	5.53	5.86	5.95	5.55
ratio	1.09	1.03	1.02	1.03	1.07	1.01

[a]Plasma collected after a 24 hour fast and 1 hour postfeeding.

[b]Ratio = postfeed value/fasted value.

[c]Refer to Table B1 and B2 for the statistical analysis.

Table A9. Summary of free plasma essential amino acids (EAA) during gestation as affected by lysine intake, mg/100 ml[abc]

Item	Lysine, %			
	0.20	0.30	0.41	0.55
Threonine				
fast	4.8	5.3	3.0	2.2
postfeed	4.7	5.3	3.2	3.4
Valine				
fast	4.0	4.6	3.4	3.3
postfeed	3.7	4.7	4.2	4.5
Methionine				
fast	1.7	1.7	1.4	1.1
postfeed	1.4	2.1	2.1	2.5
Isoleucine				
fast	2.5	2.7	2.0	1.5
postfeed	2.1	3.4	2.7	3.0
Leucine				
fast	4.4	5.0	3.8	3.4
postfeed	2.7	5.2	4.5	4.3
Phenylalanine				
fast	2.1	2.3	1.6	1.7
postfeed	1.6	2.1	2.2	2.4
Histidine				
fast	2.1	2.3	2.5	2.6
postfeed	1.7	2.0	2.9	3.2
Arginine				
fast	3.7	4.6	4.6	3.6
postfeed	4.4	7.1	5.7	4.2
Total EAA less lysine				
fast	25.3	28.5	22.3	19.3
postfeed	22.3	32.0	27.6	27.5

[a]Plasma collected after a 24 hour fast and 1 hour postfeeding.

[b]Analysis determined from sample pooled by treatment, period of reproduction and parity.

[c]Refer to Table B3 and B4 for the statistical analysis.

Table A10. Summary of free plasma nonessential amino acids (NEAA) during gestation as affected by lysine intake, mg/100ml[abc]

Item	Lysine, %			
	0.20	0.30	0.40	0.55
Aspartic acid				
fast	0.4	0.5	0.4	0.2
postfeed	0.3	0.5	0.3	0.3
Serine				
fast	3.0	4.1	3.7	3.1
postfeed	2.6	3.6	3.0	3.1
Asparagine				
fast	1.3	1.8	1.5	1.4
postfeed	1.5	2.2	1.8	2.0
Glutamic acid				
fast	6.2	8.2	7.5	5.0
postfeed	5.0	7.2	7.6	6.5
Glutamine				
fast	7.0	12.2	6.9	11.3
postfeed	6.9	10.1	5.7	9.9
Proline + Glycine				
fast	10.1	11.7	11.5	8.6
postfeed	6.6	8.6	10.7	11.2
Alanine				
fast	8.0	10.8	8.2	7.0
postfeed	8.1	10.1	10.0	11.4
Citrulline				
fast	2.5	2.6	1.7	1.8
postfeed	1.7	1.9	1.7	2.1
Cystine				
fast	2.4	2.7	2.5	2.6
postfeed	2.5	3.0	3.2	3.6
Tyrosine				
fast	2.2	2.4	2.1	1.9
postfeed	1.9	2.5	2.4	2.5

[a]Plasma collected after a 24 hour fast and 1 hour postfeeding.

[b]Analysis determined from samples pooled by treatment, period of reproduction and parity.

[c]Refer to Table B5 and B6 for the statistical analysis.

Table A10 (Continued)

Item	Lysine, %			
	0.20	0.30	0.40	0.55
Ornithine				
fast	1.4	2.1	1.4	1.5
postfeed	1.4	1.8	1.5	1.7
Total NEAA				
fast	44.4	59.1	47.5	44.9
postfeed	38.7	51.4	47.1	54.5

Table A11. Summary of free plasma essential amino acids (EAA) and plasma urea nitrogen during lactation as affected by lysine intake during gestation, mg/100ml[ab]

Item	Lysine, %			
	0.20	0.30	0.41	0.55
Lysine	1.0	1.5	1.4	1.1
Threonine	4.1	2.6	3.6	3.5
Valine	4.9	2.8	4.0	3.9
Methionine	1.3	0.8	1.0	1.1
Isoleucine	1.9	1.0	1.5	1.6
Leucine	4.4	2.2	3.6	3.7
Phenylalanine	1.9	1.7	2.9	2.6
Histidine	3.7	2.6	3.0	2.3
Arginine	5.6	4.9	5.6	3.7
Total EAA less lysine	27.8	18.6	25.2	22.2
Plasma urea nitrogen	13.8	12.9	13.0	11.8

[a]Lysine and urea analyzed from individual samples and others analyzed from samples pooled by treatment and parity.

[b]Plasma samples were collected 4 1/2 hours postfeeding.

Table A12. Summary of free plasma nonessential amino acids (NEAA) during lactation as affected by lysine intake during gestation, mg/100 ml[ab]

Item	Lysine, %			
	0.20	0.30	0.41	0.55
Aspartic acid	0.5	0.2	0.4	0.6
Serine	4.1	1.9	2.6	3.8
Asparagine	3.1	1.7	0.7	3.9
Glutamic acid	7.0	3.8	5.4	7.6
Glutamine	13.1	5.8	9.5	15.8
Proline plus glycine	11.3	5.1	4.3	12.3
Alanine	11.2	6.2	8.3	13.4
Cystine	1.3	1.2	1.2	2.4
Tyrosine	4.2	2.7	3.0	4.9
Ornithine	2.2	1.8	1.1	1.9
Total NEAA	57.9	30.5	36.6	66.5

[a]Determined from samples pooled by treatment and parity.

[b]Plasma samples were collected 4 1/2 hours postfeeding.

Table A13. Summary of gestation nitrogen metabolism as affected by lysine intake, g/day[a]

Item	Lysine, %			
	0.20	0.30	0.41	0.55
Nitrogen intake, g/day	25.5	25.4	25.7	25.5
Fecal nitrogen, g/day	5.1	4.2	4.4	4.3
Urine nitrogen, g/day	16.1	14.4	12.7	11.7
Nitrogen retained, g/day	4.3	6.8	8.5	9.4
Apparent nitrogen digestibility coefficient (ANDC)[b]	80.1	83.4	82.7	83.1

[a]Refer to Table B7 for the statistical analysis.

[b]ANDC = (NI - FN/NI) 100.

Table A14. Summary of gestation nitrogen metabolism as affected by the period and parity of reproduction, g/day[a]

Item	Period of Reproduction					
	Premate	20 days postcoitum	60 days postcoitum	95 days postcoitum	Parity I	Parity II
Nitrogen intake	25.5	25.5	25.5	25.5	25.5	25.5
Fecal nitrogen	4.1	4.4	4.4	5.1	4.4	4.6
Urine nitrogen	15.6	13.1	14.3	11.9	14.6	12.9
Nitrogen retained	5.8	7.9	6.8	8.5	6.6	8.0
Apparent nitrogen digestibility coefficient[b]	84.0	82.6	82.8	80.0	82.9	81.8

[a]Refer to Table B7 for the reproductive analysis.

[b]ANDC = (NI - FN/NI) 100.

Table A15. Summary of lactation nitrogen metabolism as affected by lysine intake during gestation, g/day[a]

Item	Lysine, %			
	0.20	0.30	0.41	0.55
Nitrogen intake	98.5	99.6	93.3	98.8
Fecal nitrogen	16.8	15.8	16.2	16.3
Urine nitrogen	29.1	29.9	28.3	30.9
Nitrogen retained	52.6	53.9	48.7	51.6
Milk nitrogen	32.2	36.8	40.6	41.0
Nitrogen balance[b]	20.4	17.1	8.1	10.6

[a]Refer to Table B9 for the statistical analysis.

[b]Nitrogen balance = nitrogen retained - milk nitrogen.

Table A16. Summary of lactation nitrogen metabolism as affected by parity, g/day[a]

Item	Parity	
	I	II
Nitrogen intake	92.1	103.1
Fecal nitrogen	15.5	17.1
Urine nitrogen	27.8	31.3
Nitrogen retained	48.8	54.7
Milk nitrogen	32.5	42.8
Nitrogen balance[b]	16.3	11.8

[a]Refer to Table B9 for the statistical analysis.

[b]Nitrogen balance = nitrogen retained - milk nitrogen.

Table A17. Summary of reproductive performance as affected by lysine intake during gestation[a]

Item	Lysine, %			
	0.20	0.30	0.41	0.55
Total pigs born/litter	11.1	9.2	10.6	9.8
Live pigs born/litter	9.6	8.3	10.3	9.1
Total litter weight, kg	12.4	12.0	13.5	12.8
Litter weight of live pigs, kg	11.1	11.1	13.1	11.8

[a]Refer to Table B8 for the statistical analysis.

Table A18. Summary of baby pig performance, sow milk yield and sow milk quality as affected by lysine intake during gestation[a]

Item	Lysine, %			
	0.20	0.30	0.41	0.55
7 day weight per pig, kg	2.0	2.4	2.4	2.4
14 day weight per pig, kg	2.8	3.4	3.4	3.5
21 day weight per pig, kg	3.8	4.5	4.5	4.6
Total lactation gain, kg	2.6	3.1	3.2	3.2
Milk nitrogen, g/day	32.2	36.8	40.6	41.0
Milk solids, g/day	683.2	800.2	892.2	911.3
Milk yield, kg/day	4.2	4.7	5.1	5.3
Milk protein (%N x 6.38), %	5.0	5.0	5.3	5.0

[a]Refer to Table B9 and B10 for the statistical analysis.

Table A19. Summary of reproductive performance, baby pig gain and milk criteria as affected by parity[a]

Item	Parity	
	I	II
Total pigs born/litter	9.8	10.6
Live pigs born/litter	8.8	9.8
Total litter weight, kg	11.7	13.6
Litter weight of live pigs, kg	10.6	12.9
7 day weight/pig, kg	2.2	2.4
14 day weight/pig, kg	3.1	3.4
21 day weight/pig, kg	4.2	4.5
21 day gain/pig, kg	2.9	3.1
Milk nitrogen, g/day	32.5	42.8
Milk solids, g/day	708.7	935.1
Milk yield, kg/day	4.0	5.7
Milk protein (% N x 6.38), %	5.3	4.8

[a]Refer to Table B8, B9 and B10 for the statistical analysis.

Table A20. Summary of sow weight changes as affected by the lysine intake during gestation, kg[ab]

Item	Lysine, %			
	0.20	0.30	0.41	0.55
Initial weight	123.9	134.5	128.4	130.1
Weight at mating	121.8	134.7	130.9	131.8
Weight 30 days postmating	128.4	138.3	134.2	136.3
Weight 60 days postmating	134.9	146.0	142.2	144.8
Weight 95 days postmating	141.9	152.0	151.3	152.3
Gross gestation gain[c]	25.6	23.7	25.8	27.6
Net gestation gain[d]	11.7	12.0	12.8	12.1
Weight prepartum	147.3	158.5	156.7	159.4
Weight postpartum	133.5	146.7	143.7	143.9
Weight at weaning	138.7	149.0	140.9	144.6
Lactation weight change[e]	5.3	2.2	-2.8	0.7

[a]Values cumulated over two reproductions.

[b]Refer to Table B11 and B12 for the statistical analysis.

[c]Gross gestation gain = prepartum weight - mating weight.

[d]Net gestation gain = postpartum weight - mating weight.

[e]Lactation weight change = weight at weaning (21 days) - postpartum weight.

Table A21. Summary of sow weight changes as affected by parity, kg[a]

Item	Parity I	Parity II
Initial weight	114.8	143.6
Weight at mating	121.0	138.6
Weight 30 days postmating	128.5	140.1
Weight 60 days postmating	138.1	145.9
Weight 95 days postmating	147.8	150.9
Gross gestation gain[b]	34.7	16.7
Net gestation gain[c]	22.3	2.0
Weight prepartum	155.7	155.3
Weight postpartum	143.3	140.6
Weight at weaning	145.1	141.5
Lactation weight change[d]	1.8	0.9

[a]Refer to Table B11 and B12 for the statistical analysis.

[b]Gross gestation gain = prepartum weight - mating weight.

[c]Net gestation gain = postpartum weight - mating weight.

[d]Lactation weight change = weight at weaning (21 days) - postpartum weight.

Table A22. Summary of sow backfat changes as affected by lysine intake during gestation, cm[ab]

Item	Lysine, % 0.20	0.30	0.41	0.55
Premating	2.3	3.1	2.7	2.6
30 days postmating	2.7	2.9	2.7	2.5
60 days postmating	2.6	2.8	2.8	2.6
95 days postmating	2.6	2.9	2.7	2.6
Gestation change	0.3	-0.2	0.0	0.0
Prepartum	2.4	2.6	2.5	2.5
Backfat at weaning	2.2	2.4	2.2	2.2
Lactation change	-0.2	-0.2	-0.4	-0.4

[a]Refer to Table B13 and B14 for the statistical analysis.

[b]Backfat values are the mean of probes made at the first rib, last rib and last lumbar vertebra all 4.4 cm to the right of the midline of the back.

Table A23. Summary of sow backfat changes as affected by parity, cm[a]

Item	Parity	
	I	II
Premating	3.0	2.4
30 days postmating	3.0	2.4
60 days postmating	3.0	2.4
95 days postmating	3.2	2.2
Gestation change	0.2	-0.2
Prepartum	2.9	2.1
Backfat at weaning	2.7	1.8
Lactation change	-0.2	-0.3

[a]Refer to Table B13 and B14 for the statistical analysis.

Table A24. Summary of carcass measures as affected by lysine intake during gestation[a]

Item	Lysine, %			
	0.20	0.30	0.41	0.55
Live weight, kg	136.7	134.1	130.2	130.3
Carcass weight, kg	96.2	98.3	93.0	93.8
Loineye area, sq cm	26.3	37.4	34.1	37.4
Carcass backfat, cm	2.8	2.7	2.4	2.3
Carcass length, cm	91.6	90.5	90.3	89.7
Carcass yield, percent	69.9	72.5	70.4	71.7
Ham and loin, percent	40.9	40.6	42.6	42.1
Lean cuts, percent	61.3	63.5	62.4	64.2

[a]Refer to Table B15 for the statistical analysis.

APPENDIX B

Table B1. Analysis of variance of plasma free lysine during gestation

Source	d.f.	Mean Squares					
		Lysine fasted	d.f.	Lysine postfeed	d.f.	Lysine ratio
Treatment	3	41.7***	3	311.2***	3	16.5***
Linear	1	109.3***	1	887.5***	1	29.3***
Quadratic	1	14.7	1	28.7	1	7.4
Cubic	1	0.9	1	17.4	1	12.9*
Period	3	1.6	3	13.0	3	0.1
Linear	1	0.2	1	1.2	1	0.1
Quadratic	1	2.3	1	17.8	1	0.0
Cubic	1	2.2	1	19.9	1	0.1
Replicate	5	3.4	5	9.3	5	5.4
Parity	1	7.2	1	38.4*	1	0.7
Treat x Rep	15	3.4	15	12.5	15	2.2
Treat x Period	9	2.2	9	3.9	9	1.1
Treat x Parity	3	2.1	3	13.9	3	0.4
Period x Parity	3	3.9	3	11.5	3	6.4*
Remainder	144	2.8	142	7.5	142	1.8
Total	186		185		185	

*$P \leq .05$.
***$P \leq .005$.

Table B2. Analysis of variance of plasma urea nitrogen (PUN) during gestation

Source	d.f.	Mean Squares				
		PUN fasted	d.f.	PUN postfeed	d.f.	PUN ratio
Treatment	3	62.0**	3	82.0**	3	0.1
Linear	1	153.4***	1	207.8***	1	0.1
Quadratic	1	28.1	1	32.9	1	0.3
Cubic	1	4.6	1	5.1	1	0.0
Period	3	2.4	3	6.2	3	0.3
Linear	1	0.1	1	2.3	1	0.4
Quadratic	1	6.2	1	15.3	1	0.3
Cubic	1	0.9	1	1.0	1	0.2
Replicate	5	9.8***	5	12.9***	5	0.8*
Parity	1	1.5	1	10.2	1	1.8*
Treat x Rep	15	11.6***	15	13.8***	15	0.5
Treat x Period	9	2.8	9	2.8	9	0.2
Treat x Parity	3	1.3	3	2.9	3	0.2
Period x Parity	3	1.8	3	4.3	3	0.5
Remainder	135	2.7	136	2.9	133	0.3
Total	177		179		176	

*$P \leq .05$.
**$P \leq .01$.
***$P \leq .005$.

Table B3. Analysis of variance of pooled essential free plasma amino acids (EAA) collected after fasting

Source	d.f.	Mean Squares			
		Threonine	Valine	Methionine	Iosleucine
Treatment	3	17.87*	3.03	0.72*	2.18*
Linear	1	44.34***	4.65*	2.01***	5.56*
Quadratic	1	1.03	0.35	0.08	0.45
Cubic	1	8.32	4.08	0.06	0.54
Period	3	8.00	3.37	0.53	2.18*
Linear	1	12.58	5.72*	1.01*	3.49*
Quadratic	1	4.86	2.27	0.52	2.80
Cubic	1	6.57	2.13	0.05	0.23
Treat x Period	9	3.06	0.82	0.11	0.55
Remainder	16	8.25	5.62	0.43	1.07
Total	31				

*$P \leq .05$.

**$P \leq .01$.

***$P \leq .005$.

Mean Squares				
Leucine	Phenylalanine	Histidine	Arginine	Total EAA
4.02	0.97	0.52	2.44	125.10
8.21*	1.76*	1.44*	0.10	253.12*
0.84	0.00	0.11	7.16	42.45
3.01	1.13	0.00	0.06	79.74
3.33	1.01	0.96	1.55	133.35
3.60	1.45	2.77*	3.22	236.49*
4.92	1.37	0.07	0.20	104.15
1.45	0.22	0.03	1.24	59.42
1.46	0.30	0.27	1.75	39.52
8.16	1.50	2.05	2.42	159.87

Table B4. Analysis of variance of pooled essential free plasma amino acids (EAA) collected postfeeding

Source	d.f.	Mean Squares			
		Threonine	Valine	Methionine	Isoleucine
Treatment	3	8.32*	1.50	1.64	2.62*
Linear	1	14.93***	1.52	3.80*	1.48
Quadratic	1	0.00	0.66	0.33	1.60
Cubic	1	10.01*	2.32	0.78	4.80*
Period	3	0.32	1.12	0.08	0.25
Linear	1	0.25	1.36	0.01	0.24
Quadratic	1	0.68	0.25	0.13	0.20
Cubic	1	0.01	1.76	0.10	0.30
Treat x Period	9	1.71	1.19	0.57	0.53
Remainder	16	10.03	7.82	2.05	4.07
Total	31				

*$P \leq .05$.

**$P \leq .01$.

***$P \leq .005$.

Mean Squares				
Leucine	Phenylalanine	Histidine	Arginine	Total EAA
8.50**	0.93	4.31	14.63	127.22
4.91	2.35	12.12*	3.11	36.03
13.65**	0.23	0.27	30.16	166.33
6.95*	0.22	0.54	10.61	179.31
0.83	0.05	1.40	5.41	24.58
2.10	0.00	3.10	0.20	15.63
0.14	0.00	0.57	3.35	2.25
0.24	0.17	0.51	12.67	55.85
1.10	0.50	1.55	12.52	78.49
6.72	1.46	3.69	3.41	231.77

Table B5. Analysis of variance of pooled nonessential free plasma amino acids (NEAA) collected after fasting

Source	d.f.	Mean Square				
		Aspartic acid	Serine	Asparagine	Glutamic acid	Glutamine
Treatment	3	0.06	1.84	0.51	11.77	62.03*
Linear	1	0.10	0.03	0.03	4.53	21.61
Quadratic	1	0.10	4.55	0.76	28.37	0.01
Cubic	1	0.00	0.94	0.73	2.39	164.48***
Period	3	0.06	2.60	0.56	21.68	19.60
Linear	1	0.12	4.19	0.87	36.49*	58.21
Quadratic	1	0.04	1.45	0.64	24.77	0.57
Cubic	1	0.01	2.16	0.18	3.79	0.02
Treat x Period	9	0.03	1.04	0.18	6.14	11.66
Remainder	16	0.07	5.29	0.85	24.30	44.46
Total	31					

*$P \leq .05$.
***$P \leq .005$.

Table B5 (Continued)

Mean Square						
Proline plus Glycine	Alanine	Citralline	Cystine	Tyrosine	Ornithine	Total NEAA
16.68	21.04	1.72	0.19	0.36	0.85	378.37*
12.63	15.96	3.37*	0.11	0.57	0.15	69.61
37.36	23.07	0.04	0.13	0.30	0.51	437.32
0.04	24.08	1.75	0.32	0.22	1.88	628.19*
41.51*	52.04**	1.43	0.91	1.59*	0.55	419.23*
62.75*	102.93***	3.49*	1.44	2.77*	0.95	555.56*
34.32	43.67*	0.16	1.24	1.70*	0.34	497.58*
27.47	9.53	0.66	0.05	0.30	0.35	204.56
7.98	6.76	0.50	0.30	0.29	0.42	90.76
43.14	29.02	1.61	1.55	1.74	1.31	836.60

**$P \leq .01$.

Table B6. Analysis of variance of pooled nonessential free plasma amino acids (NEAA) collected postfeeding

Source	d.f.	Mean Square				
		Aspartic acid	Serine	Asparagine	Glutamic acid	Glutamine
Treatment	3	0.04	1.40	0.61	7.08	39.69*
Linear	1	0.00	0.20	0.43	4.52*	9.10
Quadratic	1	0.02	1.41	0.29	10.38*	6.49
Cubic	1	0.09*	2.50	1.10	6.35	103.48***
Period	3	0.02	0.17	0.08	6.47*	5.67
Linear	1	0.01	0.06	0.17	0.00	16.94
Quadratic	1	0.05	0.35	0.06	18.66***	0.06
Cubic	1	0.00	0.08	0.00	0.76	0.02
Treat x Period	9	0.01	0.49	0.22	1.27	6.92
Remainder	16	0.05	3.77	1.51	18.64	43.89
Total	31					

*$P \leq .05$.

***$P \leq .005$.

Table B6 (Continued)

Mean Square						
Proline plus Glycine	Alanine	Citralline	Cystine	Tyrosine	Ornithine	Total NEAA
35.58	14.78	0.29	1.61	0.70	0.21	376.42
97.61**	37.69	0.44	4.56*	1.16	0.27	701.42*
8.42	1.10	0.15	0.11	0.64	0.05	55.88
0.70	5.55	0.28	0.18	0.30	0.42	371.94
1.99	6.90	0.42	0.10	0.26	0.24	49.18
0.38	4.36	0.92	0.02	0.64	0.68	1.36
5.54	15.27	0.01	0.24	0.01	0.03	143.60
0.06	1.07	0.33	0.04	0.13	0.00	4.09
8.66	10.16	0.48	0.84	0.36	0.31	124.00
37.45	42.06	0.65	2.49	2.32	0.88	890.87

*$P \leq .05$.
**$P \leq .01$.

Table B7. Analysis of variance of gestation nitrogen metabolism

Source	d.f.	Mean Squares				
		Nitrogen intake	Fecal nitrogen	Urine nitrogen	Nitrogen retained	Nitrogen apparent digestibility coefficient
Treatment	3	0.6	6.1	155.4***	210.8***	92.4
Linear	1	0.1	6.7	446.5***	581.4***	109.3
Quadratic	1	0.2	5.1	18.9	50.6	84.8
Cubic	1	1.4	6.4	0.7	0.3	83.1
Period	3	0.0	8.6**	118.1***	66.9***	132.5**
Linear	1	0.0	21.3***	252.2***	126.8***	327.7***
Quadratic	1	0.0	1.8	0.0	2.3	28.0
Cubic	1	0.0	2.7	102.0***	71.5*	42.0
Replicate	5	0.0	4.9	7.7	10.3	74.9
Parity	1	0.0	3.4	131.8***	92.8**	52.3
Treat x Rep	15	0.0	6.3*	19.0	27.6***	97.2***
Treat x Period	9	0.0	1.7	4.3	4.5	26.3
Treat x Parity	3	0.0	0.4	17.3	14.2	6.3
Period x Parity	3	0.0	7.6*	48.2***	52.1***	116.6*
Remainder	141	0.0	2.0	10.4	11.8	31.0
Total	183					

*$P \leq .05$.
**$P \leq .01$.
***$P \leq .005$.

Table B8. Analysis of variance of reproductive performance

Source	d.f.	Mean Square			
		Total pigs born	Total born alive	Total litter weight	Litter weight of live pigs
Treatment	3	7.2	8.4	4.6	10.5
Linear	1	2.0	0.3	3.5	8.9
Quadratic	1	1.7	0.6	0.9	9.0
Cubic	1	17.9	24.4	9.4	13.5
Replicate	5	22.0	15.9	22.3	11.7
Parity	1	7.0	11.2	44.8*	60.4***
Treat x Rep	15	9.6	7.8	13.1	13.1
Treat x Parity	3	1.3	1.1	1.5	1.5
Remainder	19	5.6	4.1	5.6	4.4
Total	46				

*$P \leq .05$.

***$P \leq .005$.

Table B9. Analysis of variance of lactation nitrogen metabolism and milk criteria

Source	d.f.	Mean Squares			
		Nitrogen intake	Fecal nitrogen	Urine nitrogen	Nitrogen retained
Replicate	5	213.2	32.5	40.3	98.8
Treatment	3	100.8	1.7	13.8	57.3
Linear	1	10.8	0.2	9.7	35.0
Quadratic	1	99.2	3.1	11.4	23.1
Cubic	1	192.5	1.7	20.5	113.7
Parity	1	1383.9***	30.8	135.6	399.7
Treat x Rep	15	65.8	11.5	62.4	63.0
Treat x Parity	3	77.8	28.1	167.2	59.4
Remainder	19	34.2	10.4	119.7	116.6
Total	46				

*$P \leq .05$.

**$P \leq .01$.

***$P \leq .005$.

Mean Squares				
Total milk nitrogen	Nitrogen balance	Total milk solids	% milk protein	Milk yield
101.8	88.9	48118.4	0.2	1769944.3
180.7*	358.1*	117549.9	0.2	2673163.1
457.4**	745.7*	305680.9*	0.1	7476368.8*
83.9	195.1	46798.8	0.2	495463.9
0.8	133.6	170.1	0.4	47656.5
1217.2	221.8	585446.7***	2.5*	32038766.9**
47.3	96.0	42348.6	0.5	1304572.8
121.0	304.7	71693.2	0.2	1547257.8
38.0	150.7	16317.8	0.4	855885.6

Table B10. Analysis of variance of pig lactation performance

Source	d.f.	Mean Square			
		7 day weight	14 day weight	21 day weight	21 day gain
Treatment	3	4.1*	9.5	14.3	8.3
Linear	1	6.9*	18.0*	28.3*	16.3
Quadratic	1	3.2	7.6	8.0	7.4
Cubic	1	2.1	2.7	6.5	1.3
Replicate	5	2.1	4.6	6.9	3.5
Parity	1	7.2***	13.5***	12.5*	6.6
Treat x Rep	15	1.1	3.1	5.7	6.6
Treat x Parity	3	0.5	1.9	4.2	6.1
Remainder	19	0.5	1.1	2.3	2.3
Total	46				

*$P \leq .05$.

***$P \leq .005$.

Table B11. Analysis of variance of sow weight changes during gestation

Source	d.f.	Mean Squares		
		Initial weight	Breeding weight	30 days postcoitum
Treatment	3	212.3	332.1	196.6
Linear	1	46.7	262.5	154.1
Quadratic	1	161.3	363.9	141.1
Cubic	1	429.1	370.0	294.2
Replicate	5	118.1	158.9	207.6
Parity	1	9429.2***	535.3***	1516.0**
Treat x Rep	15	109.6	99.8	104.9
Treat x Parity	3	58.5	62.8	60.8
Remainder	19	112.1	166.7	154.2
Total	46			

**$P \leq .01$.

***$P \leq .005$.

Mean Squares			
60 days postcoitum	95 days postcoitum	Gestation weight gain	Net gestation gain
260.9	261.4	29.9	2.8
278.5	407.2	49.2	1.5
176.8	239.1	24.5	4.8
327.4	137.8	15.9	2.1
143.1	172.9	203.4	128.0
682.9	107.7	3696.6***	4733.4***
134.3	126.5	68.3	59.2
75.0	63.2	116.7	127.1
223.5	181.1	141.6	135.8

Table B12. Analysis of variance of sow weight changes during lactation

Source	d.f.	Mean Squares			
		Prepartum weight	Postpartum weight	Weight at weaning	Lactation weight change
Treatment	3	323.7	357.4	226.8	124.5
Linear	1	539.1	304.4	24.8	155.4
Quadratic	1	199.5	452.0	64.4	175.1
Cubic	1	232.5	315.6	591.3	42.9
Replicate	5	271.5	302.4	579.4	75.9
Parity	1	1.8	87.2	148.3	8.0
Treat x Rep	15	118.3	137.1	204.0	64.7
Treat x Parity	3	10.5	32.9	5.3	33.5
Remainder	19	175.1	120.2	103.8	48.7
Total	46				

Table B13. Analysis of variance of sow backfat changes during gestation

Source	d.f.	Mean Squares				
		Prebreeding	30 days postbreeding	60 days postbreeding	95 days postbreeding	Gestation change
Treatment	3	1.3	0.3	0.2	0.3	0.5
Linear	1	0.0	0.3	0.0	0.2	0.3
Quadratic	1	2.0	0.4	0.5	0.3	0.7
Cubic	1	1.8	0.1	0.0	0.3	0.6
Replicate	5	3.8	1.8	1.9	1.3	0.9
Parity	1	4.2***	4.0***	5.2***	12.6***	2.2
Treat x Rep	15	0.5	0.4	0.4	0.5	0.3
Treat x Parity	3	0.4	0.0	0.1	0.5	0.6
Remainder	19	0.6	0.3	0.3	0.2	0.6
Total	46					

***$P \leq .005$.

Table B14. Analysis of variance of sow backfat changes during lactation

Source	d.f.	Mean Squares		
		Prepartum	Termination of lactation	Lactation change
Treatment	3	0.1	0.1	0.1
Linear	1	0.0	0.0	0.1
Quadratic	1	0.1	0.0	0.0
Cubic	1	0.1	0.3	0.1
Replicate	5	1.8	1.9	0.1
Parity	1	8.1***	9.5***	0.1
Treat x Rep	15	0.6	0.4	0.2
Treat x Parity	3	0.4	0.1	0.3
Remainder	19	0.3	0.2	0.2
Total	46			

***$P \leq .005$.

Table B15. Analysis of variance of carcass values

Source	d.f.	Mean Squares		
		Live weight	Carcass weight	Carcass yield, %
Treatment	3	44.6	30.5	5.0
Linear	1	--	--	0.2
Quadratic	1	--	--	1.0
Cubic	1	--	--	13.9
Replicate	5	177.2	177.1	3.5
Remainder	10	183.4	111.8	4.5
Total	19			

Mean Squares				
Carcass backfat	Carcass length	Loineye area	Ham and loin, %	Lean cuts, %
0.2	2.0	84.6	4.3	5.8
0.7	5.2	84.4	7.4	9.1
0.0	0.4	61.2	0.4	0.1
0.1	0.5	108.3	5.0	8.0
1.1	17.1	23.4	19.0	36.7
1.0	5.7	34.5	6.8	10.2